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This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

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Additional inventors are being named on the / *separately numbered sheets attached hereto*

TITLE OF THE INVENTION (500 characters max)

METHODS AND APPARATUS FOR MULTI-CARRIER COMMUNICATION SYSTEMS WITH ARQ

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Respectfully submitted,

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Methods and Apparatus for Multi-Carrier Communication Systems with ARQ

1 Background of the Invention

ARQ (Automatic Repeat reQuest) schemes are often used in packet communication systems to improve the transmission reliability. Hybrid ARQ is a method that combines both forward error correction (FEC) and ARQ where the previously unsuccessful transmissions are used in FEC decoding instead of being discarded. It enhances the effectiveness of FEC decoding and allows FEC blocks to be sent at high error rate operating points (see Reference [1]).

One form of the hybrid ARQ is Chase combining where the transmitter retransmits the same coded data packet (see Reference [2]). The decoder at the receiver combines these multiple copies of the transmitted packet. Another form is called incremental redundancy where, instead of sending simple repeats of the coded data packet, progressive parity packets are sent in each subsequent transmission of the packet. The decoder then combines all the transmission and therefore decodes the packet at a lower code rate.

Hybrid ARQ normally involves physical layer and is a physical layer function which controls the FEC encoding and FEC decoding functions using an embedded physical layer fast feedback channel for control signaling. At times, physical layer hybrid ARQ FEC blocks will be retransmitted the maximum number of times without success; thus, it alone cannot provide error free delivery data but permits operation at lower signal-to-interference-plus-noise ratio (SINR).

Medium access control (MAC) ARQ is an error control feature which retransmits erroneous MAC packet data unit (PDU) in a flexible fashion to achieve error free data delivery. MAC ARQ retransmissions may occur long after original transmission and the retransmission may be segmented and piggybacked on other MAC PDUS using the granularity of the defined ARQ block size.

2 Summary of the Invention

The present invention describes the methods and apparatus for hybrid ARQ in multi-carrier communication systems. It devises methods and apparatus on how to retransmit the erroneous packets by taking advantage of time, frequency, or space diversity. The invention also describes a hierarchical ARQ scheme, which combines the physical layer ARQ and the MAC ARQ and makes the multi-carrier systems more robust in high packet error environment.

The multi-carrier system mentioned in this invention can be of any special formats such as OFDM, or Multi-Carrier Code Division Multiple Access (MC-CDMA). The invention

can be applied to downlink, uplink, or both, where the duplexing technique can be either Time Division Duplexing (TDD) or Frequency Division Duplexing (FDD).

3 Brief Description of the Drawings

The present invention can be thoroughly understood from the detailed description given below and from the accompanying drawings of various embodiments of the invention, which, however, should not be taken to limit the invention to the specific embodiments, but are for explanation and understanding only.

Figure 1: The basic structure of a multi-carrier signal in the frequency domain is made up of subcarriers. Data subcarriers can be grouped into subchannels in a particular way. The pilot subcarriers are also distributed over the entire channel in a particular way.

Figure 2: The radio resource is divided into small units in both the frequency and time domains: subchannels and time slots. The basic structure of a multi-carrier signal in the time domain is made up of time slots.

Figure 3: A single ARQ process where the first transmission of the packet failed with an NACK feedback, and the second transmission of the packet (may or may not be of the same size) succeeded with an ACK feedback.

Figure 4: The system reserves at least one subchannel for the retransmission of the packets. In this case, Packet *p* and *q* from the same subscriber are transmitted in Frame *k*. Packet *p* failed and is retransmitted on the reserved channel in Frame *k+m*.

Figure 5: In this case, Packet *p* and *q* from the same subscriber are transmitted in Frame *k*. Packet *p* failed and Packet *q* succeeded. Packet *p* is retransmitted on the subchannel that was originally scheduled for Packet *r* in Frame *k+m*.

Figure 6: In this case, Packet *p* and *q* from the same subscriber are transmitted in Frame *k*. Packet *p* failed and is retransmitted on the same subchannel in Frame *k+m*.

4 Detailed Description

4.1 Multi-Carrier Communication System

The physical media resource (e.g., radio or cable) in a multi-carrier communication system can be divided in both the frequency and time domains. This canonical division provides a high flexibility and fine granularity for resource sharing.

The basic structure of a multi-carrier signal in the frequency domain is made up of subcarriers. Within a particular spectral band or channel, there are a fixed number of subcarriers. There are three types of subcarriers:

1. Data subcarriers, which carries information data;

2. Pilot subcarriers, whose phases and amplitudes are predetermined and made known to all receivers and which are used for assisting system functions such as estimation of system parameters; and
3. Silent subcarriers, which have no energy and are used for guard bands and DC carrier.

The data subcarriers can be arranged into groups called subchannels to support scalability and multiple access. The carriers forming one subchannel are not necessarily adjacent to each other. Each subscriber may use part or all of the subchannels. The concept is illustrated in Figure 1.

The basic structure of a multi-carrier signal in the time domain is made up of time slots to support multiple-access. The resource division in both the frequency and time domains is depicted in Figure 2.

Adaptive modulation and coding (AMC) is used to adjust the modulation and coding scheme to various channel conditions. It can be controlled for one individual subchannel or a group of subchannels. Table 1 is an example of the coding and modulation schemes in AMC and corresponding spectral efficiency in bits/s/Hz.

Modulation Scheme	Code Rate	Bits/s/Hz
QPSK	1/8	1/4
QPSK	1/4	1/2
QPSK	½	1
16QAM	½	2
16QAM	¾	3
64QAM	2/3	4
64QAM	5/6	5

Table 1: Examples of coding and modulation schemes in adaptive modulation and coding control

Figure 3 illustrates a single ARQ process where the first transmission of the packet failed with an NACK feedback, and the second transmission of the packet (may or may not be of the same size) succeeded with an ACK feedback

4.2 Detailed Description of the ARQ scheme

In a multi-carrier system, multiple subchannels can be used to transmit packets. In the present invention, hybrid ARQ is used for at least one of the subchannels. Without loss

of generality, we consider one such subchannel, designated as SC_i. For each of the packets transmitted over SC_i, the receiver performs the receiving process corresponding to the transmission process, and then performs error detection on the received packet. Based on the detection result, an acknowledgement (ACK or NACK) signal is provided on the return channel to inform the transmitter whether the reception of this particular packet is successful (ACK) or failed (NACK).

In one embodiment, a channel quality indicator (CQI) is transmitted along with the ACK/NACK signal to assist the selection of subchannels for the retransmission of the failed packet or the transmission of the next packet. The channel quality can be a function of one or more of the following: the signal-to-noise ratio (SNR), signal-to-interference-plus-noise ratio (SINR), bit error rate, symbol error rate, packet error rate, pilot signal power level, or signal mean square error that are measured based on the previous packet(s).

After the transmitter receives the NACK signal, it selects another subchannel, say SC_j, and retransmits the failed packet. A different subchannel is used for retransmission because it may have a different channel response and experience interference level, thereby creating frequency and time diversity effects which can be utilized at the receiver to improve the performance. At the receiver, the previously received signals, which have been stored at the physical layer, and the newly received retransmission signals are combined for the demodulation and decoding of the packet. In one embodiment, Chase combining is used where the soft samples of the same packet from previous transmission(s) and the current retransmission are combined coherently to provide additional diversity gain. In another embodiment, incremental redundancy is used where progressive parity packets are sent in each subsequent transmission of the packet. The retransmission process and the receiving process can continue until the packet is successfully received or a pre-specified number of retransmission has been reached.

In one embodiment, the transmitter reconfigures a subchannel for retransmission. This reconfiguration can be carried out in any combination of time, frequency, space, signal power, modulation, coding, or other signal domains. For example, in case of orthogonal frequency division multiple access (OFDMA), the transmitter can change the subcarrier composition of a subchannel. The newly composed subchannel may contain different subcarriers in terms of number, location, or other manners. The newly composed subchannel may also contain different training pilots in terms of number, location, or other manners.

In one embodiment, the transmitter randomly selects SC_j from the subchannels available to the transmitter for the retransmission.

In one embodiment, the transmitter knows the CQI of all or some of the subchannels, and accordingly selects a subchannel for retransmission in such a way that the system efficiency can be maximized. For example, the subchannel with the best quality is assigned for retransmission of the packet that has been failed for multiple times.

In one embodiment, the system reserves at least one subchannel for the retransmission of the packets. This scheme is illustrated in Figure 4: Packet p and q from the same subscriber are transmitted in Frame k; Packet p failed and is retransmitted on the

reserved channel in Frame $k+m$. A certain means is taken to improve the channel quality of these reserved subchannels. In one embodiment, a higher frequency reuse factor is used for these reserved subchannels in a multi-cell environment to reduce the impact of inter-cell interference. For instance, when the regular subchannels have a reuse factor of 1, the reserved subchannels have a reuse factor of 3. The transmitter may select SC_j randomly from the reserved subchannels, or select SC_j with sufficiently high quality if the transmitter knows the CQI of all or some of the reserved subchannels. In one embodiment, the transmitter uses a modulation/coding/power scheme that matches the channel quality of that subchannel(s), in which case the retransmitted packet is fitted into the subchannel(s) by rate matching such as repetition or puncturing.

In one embodiment, the transmitter is allocated at least two subchannels by the system. Upon receiving a NACK signal indicating the need of retransmission, the transmitter swaps the transmission of the two subchannels SC_i and SC_j; namely, it sends the retransmission over SC_j and sends the packet originally scheduled for SC_j over SC_i. This scheme is illustrated in Figure 5: Packet *p* and *q* from the same subscriber are transmitted in Frame *k*; Packet *p* failed and Packet *q* succeeded; then Packet *p* is retransmitted on the subchannel that was originally scheduled for Packet *r* in Frame $k+m$.

In one embodiment, the retransmission over SC_j uses the same settings, such as modulation, coding, and power, as the previous transmission over SC_j. When the packet size is different between the current transmission and previous transmission on SC_j , rate matching is used to fit the current retransmitted packet onto SC_j.

There are cases where it may be desirable for the transmitter to stay on the original subchannel for the retransmission. This scheme is illustrated in Figure 6: Packet *p* and *q* from the same subscriber are transmitted in Frame *k*; Packet *p* failed and is retransmitted on the same subchannel in Frame $k+m$. In one embodiment, there are no other subchannels available to the transmitter at the time of retransmission, so the transmitter selects $SC_j = SC_i$. In another embodiment, the transmitter has the knowledge about the quality of all or some of the subchannels, and finds that the quality of SC_i is good or even the best among all the subchannels, so the transmitter selects $SC_j = SC_i$. In yet another embodiment, the channel quality of SC_i is good and the modulation/coding index is high (16QAM or 64QAM), so the transmitter selects $SC_j = SC_i$. It should be note, however, that the transmitter may lower down the modulation/coding scheme in the case of retransmission based on the channel quality report from previously transmitted packets on the said subchannel.

In one embodiment, multiple subscribers may share one subchannel through, for example, time division multiplexing. Then multiple ARQ processes, each corresponding to a subscriber, can be carried out in parallel. The above described methods for retransmission can also be applied.

In the above methods, several different retransmission schemes are described. In one embodiment, which retransmission scheme to use is dictated through higher layer messaging so that the receiver knows which subchannel the retransmitted packet uses. In another embodiment, the retransmission information is embedded in the header of each retransmitted packet.

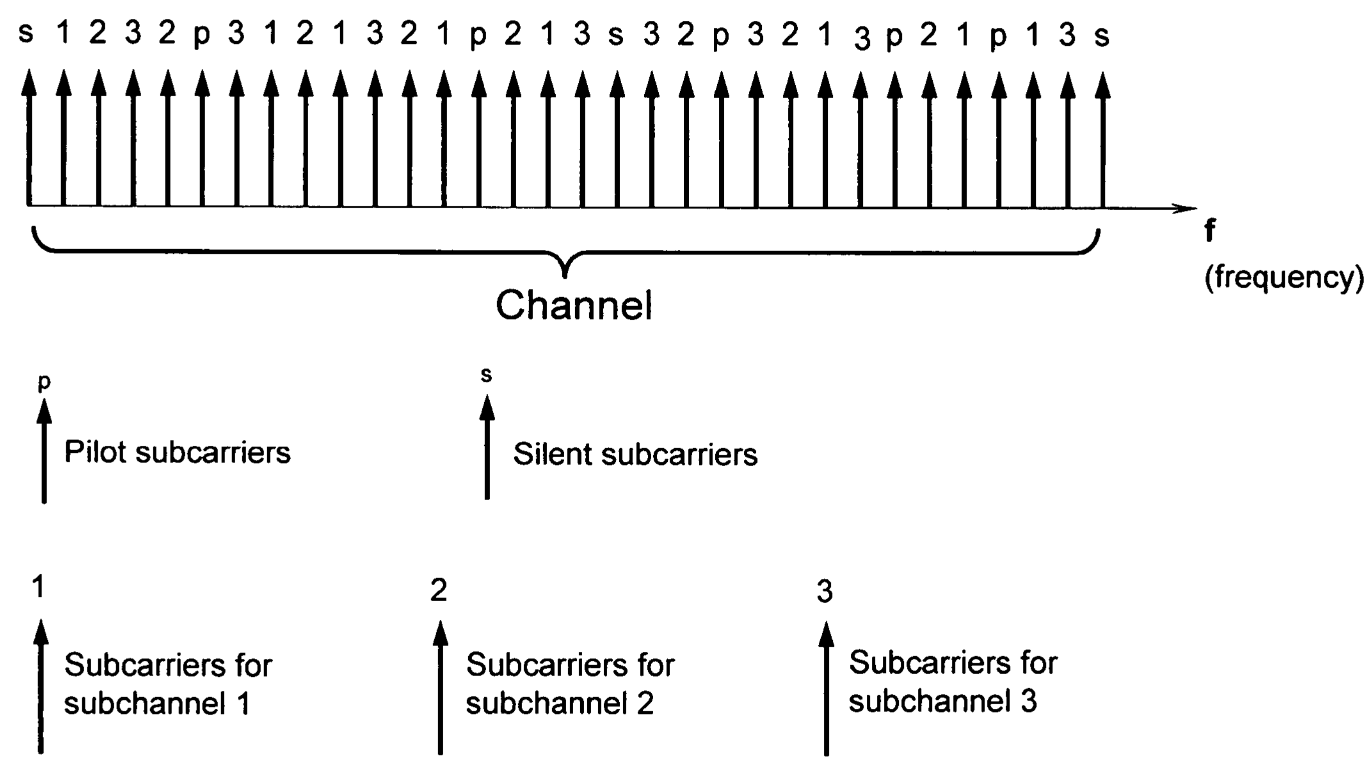
In one embodiment, a hierarchical ARQ process is implemented for a packet stream. The process includes an outer loop and at least one, possibly multiple, inner loops. The outer loop operates at higher layer, for example, the radio link protocol (RLP) layer, and uses a traditional ARQ, for example, sliding window selective-retransmission ARQ. The inner loops operate at a lower layer, for example, the physical layer, and uses hybrid ARQ with retransmission methods described in the above embodiments.

The parameters for both outer and inner loops can be changed depending on applications or unit processing capabilities. For example, the number of retransmissions for the inner loop is less for delay-sensitive applications than for other delay-insensitive applications using TCP. In one embodiment, the outer loop is removed for the UDP packet stream such as VoIP packets.

5 Reference

[1] S. B. Wicker, Error Control Systems for Digital Communication and Storage, Prentice-Hall, Inc., 1995.

[2] D. Chase, "Code Combing: A maximum-likelihood decoding approach for combining an arbitrary number of noisy packets," *IEEE Trans. on Commun.*, Vol. 33, pp.593-607, May, 1985.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f
(frequency)
Channel
p
Pilot subcarriers
s
Silent subcarriers
1
Subcarriers for subchannel 1
2
Subcarriers for subchannel 2
3
Subcarriers for subchannel 3

Figure 1

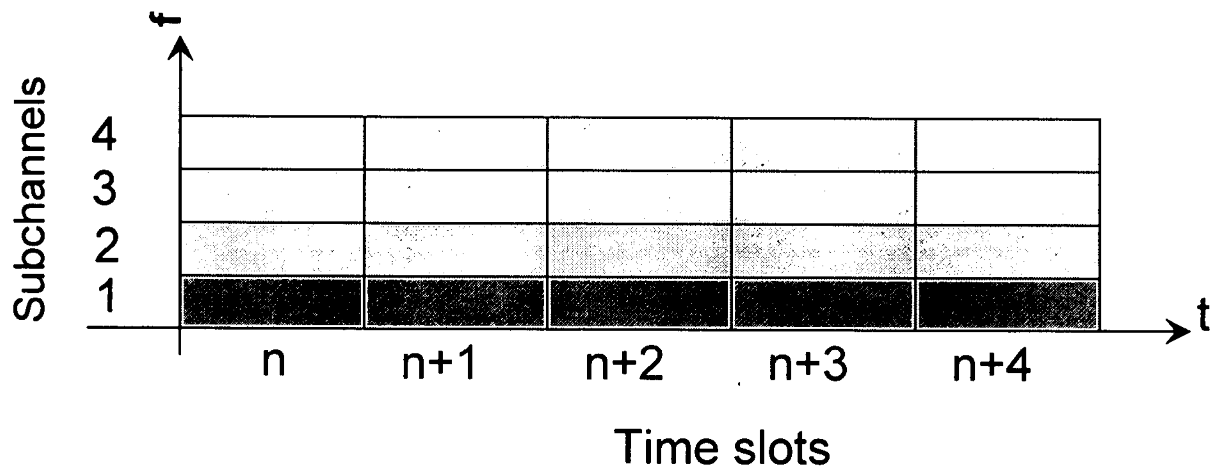
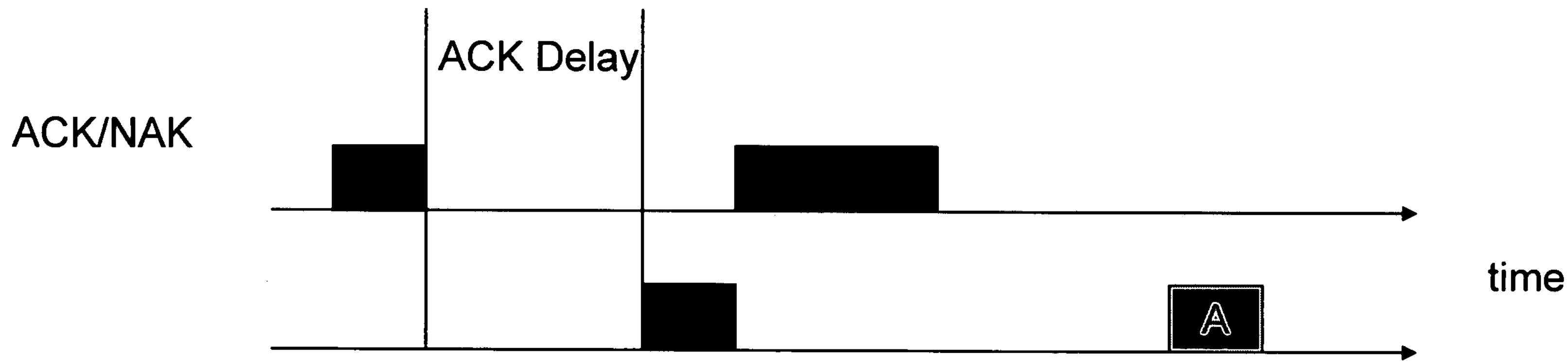
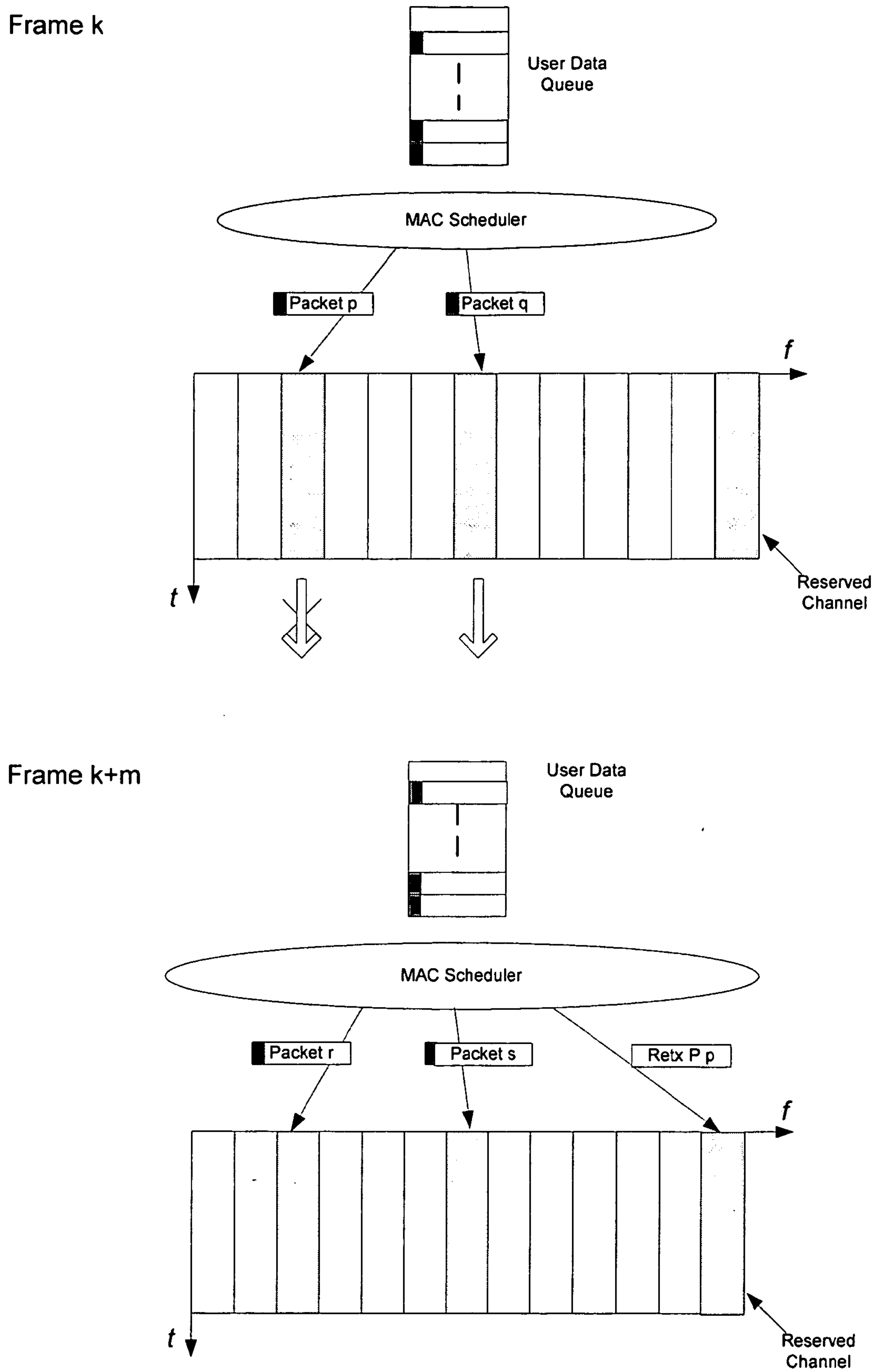


Figure 2



Single ARQ Process

Figure 3



Frame k
User Data Queue
MAC Scheduler
Packet p
Packet q
f
t
Reserved Channel
Frame k+m
User Data Queue
MAC Scheduler
Packet r
Packet s
Retx P p
f
t
Reserved Channel

Figure 4

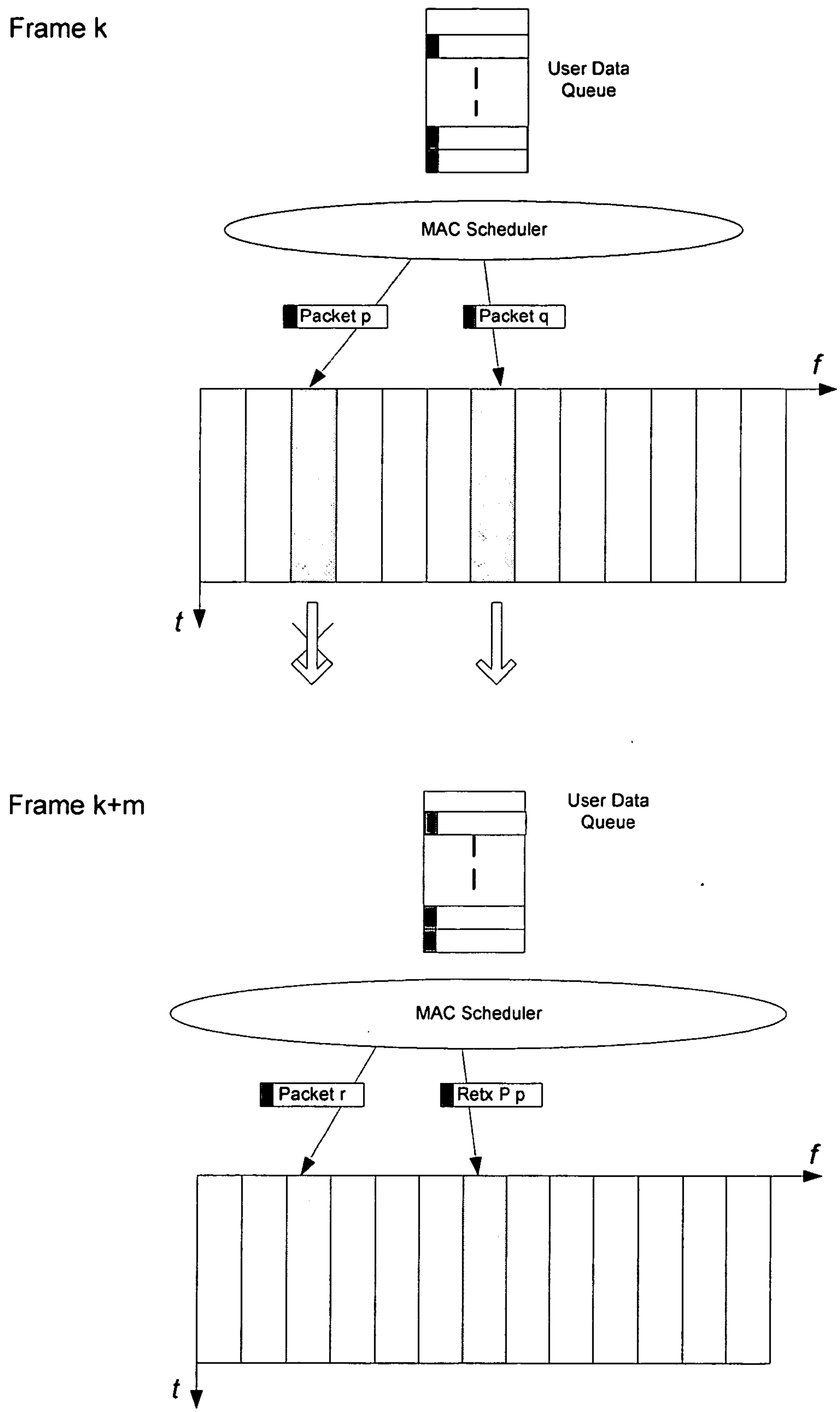

Frame k
User Data Queue
MAC Scheduler
Packet p
Packet q
f
t
Frame k+m
User Data Queue
MAC Scheduler
Packet r
Retx P p
f
t

Figure 5

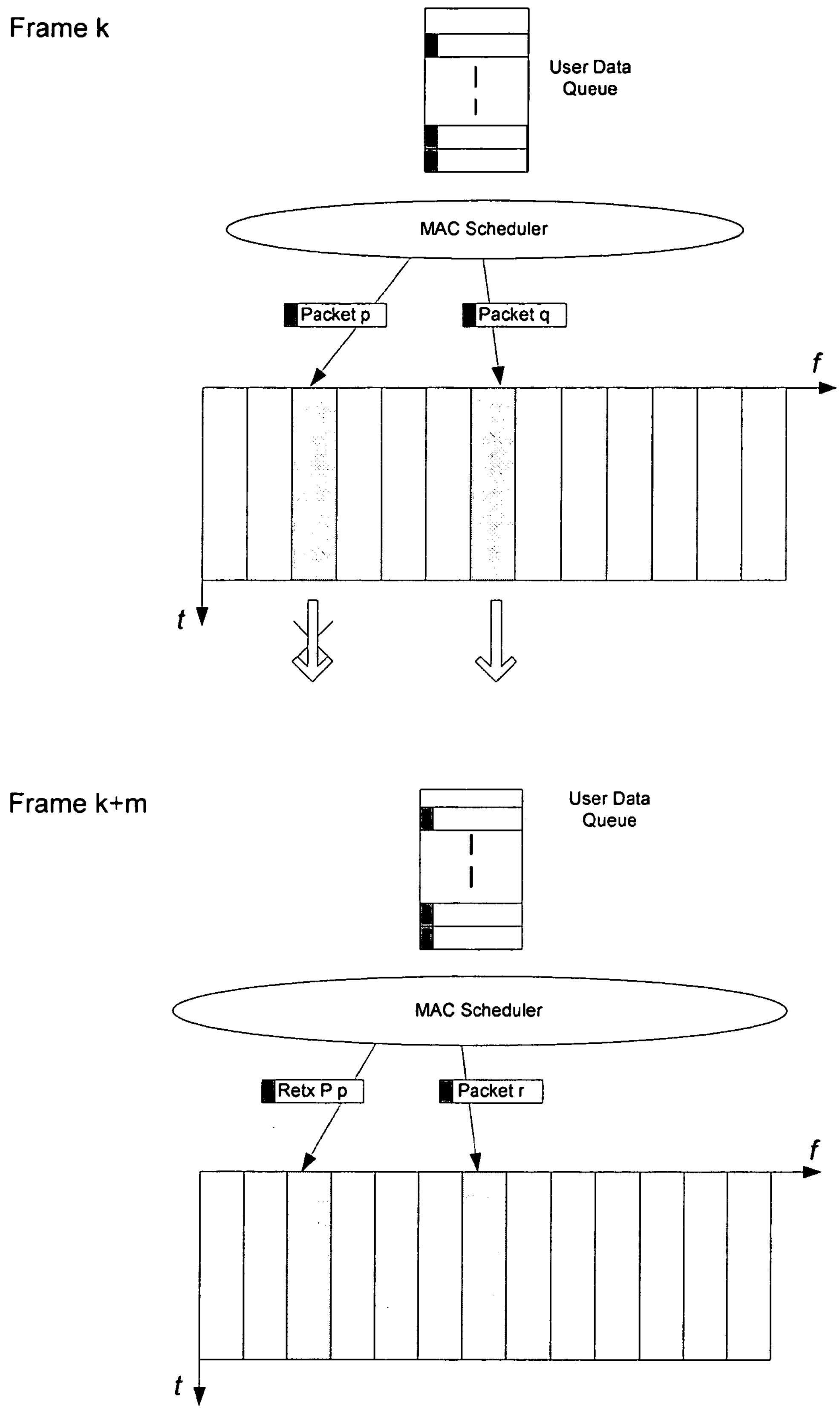

Frame k
User Data
Queue
MAC Scheduler
Packet p
Packet q
f
t
Frame k+m
User Data
Queue
MAC Scheduler
Retx P p
Packet r
f
t

Figure 6